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Building façades' visual reflectance and surface temperatures: a field study

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Abstract

The surface properties of building façades have implications for thermal performance of buildings and might also influence outdoor thermal comfort conditions for pedestrians. A façade surface property, which is frequently used by building engineers and specially architects, is the visual reflectance. In this paper, we present the result of a field study, which explores the relationship between the visual reflectance of building façades and the corresponding surface temperatures. A number of buildings with diverse façade colours were selected. Surface temperatures, incident solar irradiance, façades' visual reflectance, as well as ambient air temperature and relative humidity were measured. The results of the field study display non-random relationships between the building façades' visual reflectance and their surface temperatures.

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Keywords: Building façades; surface temperatures; visual reflectance; thermal performance

1. Introduction

The surface properties of building façades have implications for thermal performance of buildings (indoor temperatures, heating and cooling loads). The façade surface temperature might also influence outdoor thermal comfort conditions for pedestrians. The albedo of building surfaces is known to significantly affect their surface temperature. A related surface property, which is frequently used by building engineers and specially architects is

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the visual reflectance. It is defined as the ratio of reflected to incident illuminance. In this paper, we present the result of a field study, which explores the relationship between the visual reflectance of actual building façades and the corresponding surface temperatures. A number of buildings with diverse façade colours (hence different values of visual reflectance) were selected. Given adjacent buildings with different façade colours, temperature difference could be measured under nearly identical solar irradiation. As the ground floors and upper floors of a number of buildings in the sample had also sometimes different colours, temperatures on up to four differentially reflective surfaces could be monitored simultaneously under practically identical conditions. In the course of the field study, the following parameter were measured: surface temperatures (via infrared thermography), incident solar irradiance, façades' visual reflectance (via simultaneous monitoring of the illuminance on façade the luminance values of the façade), as well as ambient air temperature and relative humidity. The results of the field study display non-random relationships between the building façades' visual reflectance and their surface temperatures. The resulting data support the development of algorithms for the estimation of surface temperature variance as a result of façades' colour. Moreover, the results contribute to a better understanding of the implications of façades' colour choice for buildings' thermal performance and pedestrians' thermal comfort.

2. Approach

To conduct the measurements, nineteen buildings in the city of Vienna were selected. These are typical residential buildings constructed in the past century. The construction of the external walls of these buildings typically involves three layers, internal plaster (4 cm), massive brick wall (49 cm), and external plaster (4 cm). The colour (and hence the visual reflectance) of the external surface of these constructions can be very different (see Fig 1). To generate the measurement data, 44 spots on the façades of the selected buildings were identified. The measurement setup was configured in a manner such that two close-by measurement spots were located on adjacent façade segments of differing colour (and thus differing visual reflectance). Thus, we could make sure that these adjacent spots were exposed to identical environmental conditions (irradiance, illuminance, air temperature, etc.). To capture these conditions at the selected locations, surface temperature, surface luminance, and incident illuminance were measured. In parallel, ambient conditions (incident irradiance, ambient air temperature, relative humidity) were monitored using mobile weather stations. Surface temperature measurements were conducted following standard procedures using an infrared (IR) camera. The processing and calibration of IR images utilized collected information on prevailing ambient temperature and relative humidity values as well as the emissivity of surfaces. The latter commodity was determined using standard sticker specimens with known emissivity attached to (and in thermal equilibrium with) façade surfaces. Incident illuminance and luminance measurements were conducted using research-level advanced equipment.

The monitored data represent surface and ambient conditions in a relatively stable temporal sense. In other words, conditions were not fluctuating in a noteworthy manner prior to each recording. To derive the visual reflectance value (ρ) for each spot, the simultaneously logged values of incident illuminance (E) and luminance (L) were deployed according to the following equation:

$$\rho = \frac{L \times \pi}{E} \tag{1}$$

Given the objective of the study, the collected empirical data was processed as follows. The difference between the simultaneously measured surface temperatures ($\Delta\theta_s$) of two spatially adjacent façade spots of different visual reflectance was calculated and treated as the dependent variable, as shown in eq. 2. Note that in this equation θ_{s1} represents the surface temperature of the façade segment with lower surface reflectance.

$$\Delta\theta_s = \theta_{s1} - \theta_{s2} \qquad [\mathrm{K}] \tag{2}$$

These differences were then plotted against potential independent variables. The main hypothesized independent variable was considered to be the difference in the visual reflectance of the corresponding spots. These differences were considered both in terms of the absolute values (see eq. 3) and in terms of relative difference, which denotes the difference between the surface reflectance values of the two spots divided by the larger surface reflectance value (see eq. 4).

$$\Delta\rho = \rho_1 - \rho_2 \tag{3}$$

$$\Delta\rho_r = \frac{\rho_1 - \rho_2}{\rho_1} \tag{4}$$

To further explore the variables influencing the surface temperatures, we also considered the prevailing ambient air temperature (θ_a) and incident irradiance (E_e).

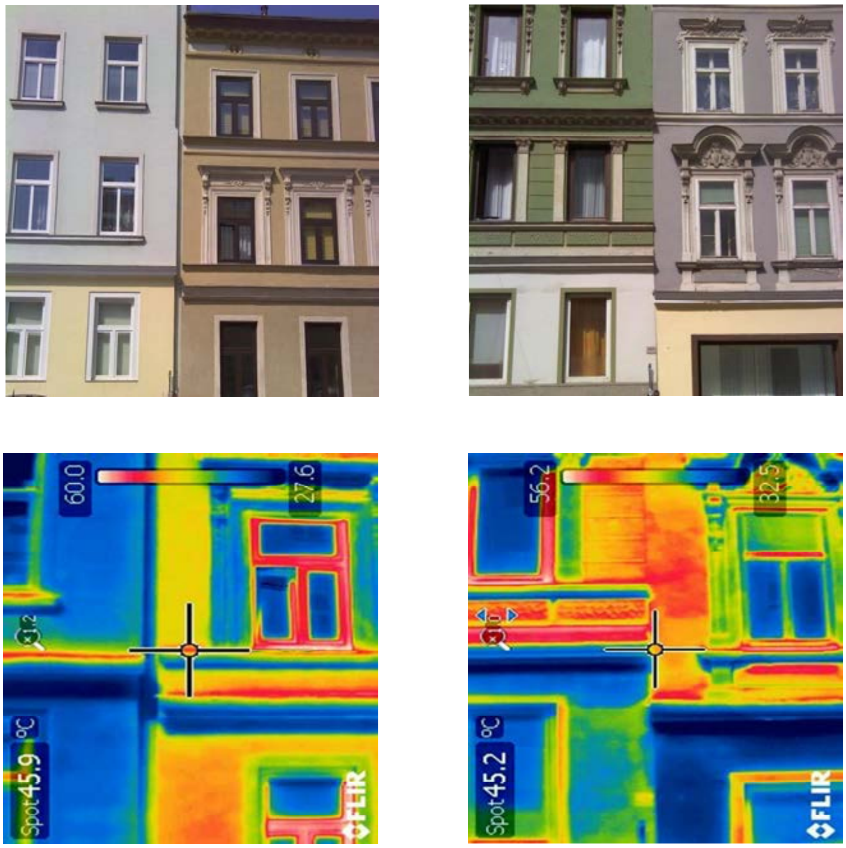

Fig. 1. Examples of the selected building façades and the respective IR images.

3. Results and discussion

The overall results of the measurements are shown in Figures 2 and 3. Thereby, surface temperature differences are plotted against corresponding values of surface reflectance differences (Fig. 2) and relative surface reflectance differences (Figure 3). These Figures confirm the intuitively expected trend: Façade surfaces with higher visual reflectance values typically display lower surface temperatures.

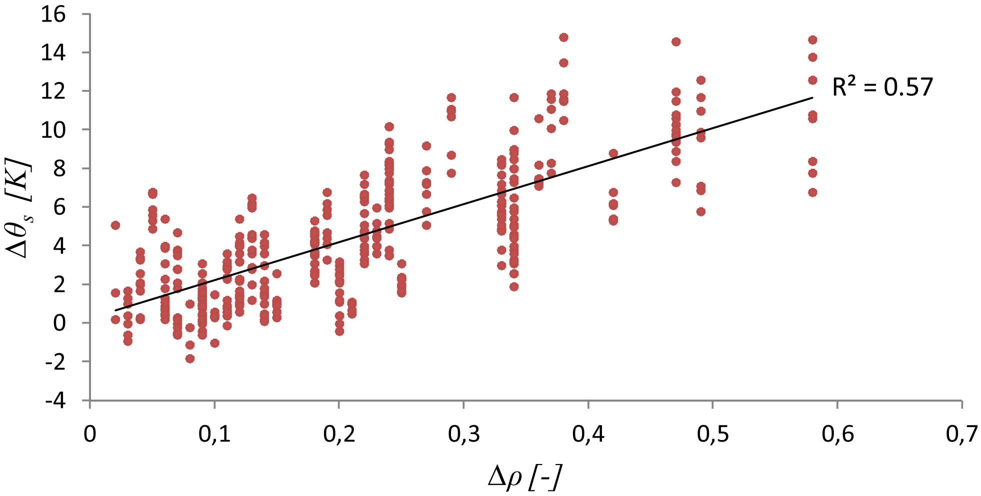

Fig. 2. Surface temperature differences vs. corresponding visual reflectance differences.

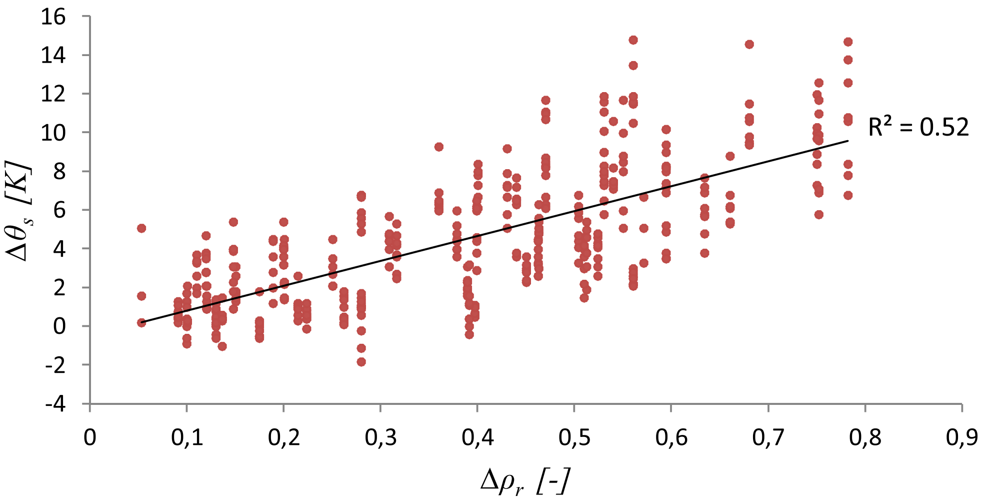

Fig. 3. Surface temperature differences vs. corresponding relative visual reflectance differences.

We could not detect a significant enough relationship between the measured ambient temperatures and surface temperature differences of the façades. However, irradiance on the façades does appreciably influence the surface temperatures. To illustrate this circumstance, Figure 4 illustrates again the relationship between surface temperature differences and relative visual reflectance differences. Thereby, respective regression lines are separately plotted for different irradiance ranges (single dots associated with individual measurements are not included in this Figure in order to maintain readability). As it can be seen from this Figure, higher irradiance ranges result in higher surface temperature differences.

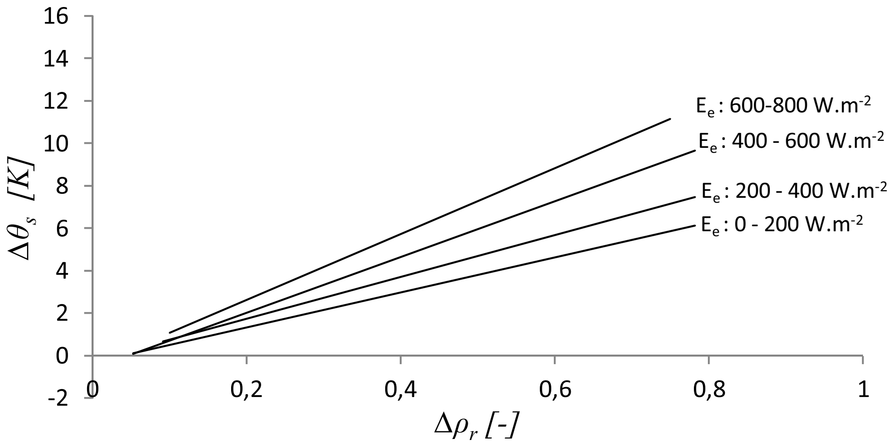

Fig. 4. Surface temperature differences plotted against relative visual reflectance differences for different ranges of incident solar radiation.

The combined influence of the incident irradiance and the visual reflectance differences shown in Figure 4 can be exploited to derive relatively simple calculation methods for the estimation of the surface temperature implications of the visual reflectance variance of building façades. To illustrate this point, Eq. 5, which is derived based on the results shown in Figure 4, specifically provides engineers and architects with a simple tool to estimate, for a given value of incident solar irradiance (E_e), the expected difference between the surface temperatures of façade surfaces of differing visual reflectance. Note that this equation is not valid for very low values of incident radiation (E_e<100 W.m^{-2}) and relative reflectance difference ($\Delta\rho_r$<0.3). Needless to say, predictions made based on this simplified relationship provide only a rough estimation. To explicitly document the predictive performance of Eq. 5, we compared the associated predictions with actual measurements. The results are displayed in Figure 5.

$$\Delta \theta_s = (0.022\ Ee + 9.3).\Delta \rho_r - 3.5 \qquad [K] \tag{5}$$

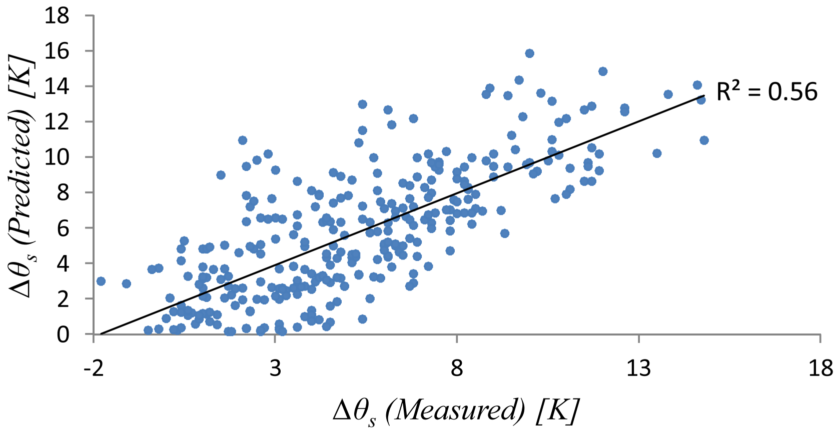

Fig. 5. Measured $\Delta\theta_s$ values versus predicted $\Delta\theta_s$ values obtained from eq. 5.

5. Conclusion

We presented the results of a field study of façade surface temperatures. Thereby, the influence of the visual reflectance of the façade surfaces was at the center of attention. The study suggests that the variance of visual reflectance results in considerable surface temperature differences. For instance, doubling the surface reflectance of a sample building's façade surface could result in a considerably cooler façade in a summer day (roughly 7 K lower surface temperature). Moreover, given information on the intensity of the incident solar radiation, the magnitude of surface temperature differences resulting from reflectance variation can be roughly estimated using simple empirically-based equations. Future efforts are expected to further enhance the empirical basis of the current exploration and address a number of its limitations. For instance, the present contribution focused on buildings with massive façades. This class of buildings is representative for a large population of buildings not only in Vienna, but across Central Europe, but it does not entail more contemporary construction methods involving, for instance, external thermal insulation. Aside from considering an extended sample of buildings of different construction types, we also currently considering the potential of numeric heat transfer simulation and its calibration via collected empirical information. Such a calibrated simulation tool would provide for a rich parametric exploration of building façade surface properties and their influence and buildings' thermal performance and pedestrians' thermal comfort.

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